

All-optical Authentication and Unlawful Access Detection by Photorefractive Four-wave Mixing

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Abstract We propose an all-optical memory with authentication and unlawful access detection using photorefractive four-wave mixing. If the data is read out by the reading beam with the improper key, we can at a glance judge whether or not the used decoding key is the proper key because the output data is hardly observed. We show the recording and retrieving process of the image information with consideration of the property of the photorefractive crystal.

1. Introduction

Optical code processing has been a focus of constant attention because we can deal with the enormous amount of the information all at once by means of the parallel processing of the light, and the code processing using the hologram has been proposed[1]. In this method, we encode the input data by the double phase encryption with the random phase mask, and recode the encoded data in the hologram. The stored data is read out by the reading beam, and this readout data is decoded by transmitting through the random phase mask, which is used in encoding process, because the phase-conjugate beam has the feature of the phase corrective operation. In case of using the improper decoding key, distorted output data is observed. Here, we previously have to know the kind or format of the original data to confirm whether or not the encode data is correctly decoded. For example, in case that the data encoded by digital code processing is inputted, it is difficult to judge immediately whether observed output data is decoded data or the data failed to decode.

In this report, we propose a new method to construct the photorefractive holographic memory with authentication and unlawful access detection using photorefractive four-wave mixing. In this memory system, the output data is hardly observed in case of using the improper decoding key. We can confirm whether the data is correct even if we don't know the kind or format of the original data. The data is encoded by adding the random phase masks to both the input signal beam and the reference beam, and recorded in the photorefractive crystal. The random phase mask of the reference beam is the encoding key. The decoding key is the complex conjugate of the random phase added to the reference beam. The decoded data is obtained by the reading beam with the proper decoding key. If the data is read out by the reading beam with the improper key, the intensity of the output data is scarcely zero because the phase of each diffraction beam shifts and the amplitude of each diffraction beam is negated each other. Therefore the output data is hardly observed. Consequently by measuring the output intensity, we can at a glance judge whether or not the used decoding key is the proper key. This function is useful for the unlawful access detection.

By use of the simulation, we show that the decoded data is restored to its original state with certain degree of

accuracy in case of retrieving with the proper decoding key and the output data is hardly observed in the case of retrieving with the improper decoding key.

2. Code processing with phase matching detection

The concept of the code processing with photorefractive four-wave mixing is shown in Fig.1, 2 and 3. Fig.1 shows the processes of the encoding and the recording. The image data passes through the mask1 which gives the spatial random phase shift $\phi_1(x, y)$ and the reference beam passes through the mask2 which gives the spatial random phase shift $\phi_2(x, y)$. In this memory system, $\phi_2(x, y)$ is the encoding key. Then the data is encoded by two random phase masks and recoded in a photorefractive crystal as the refractive index grating induced by the signal beam and the reference beam.

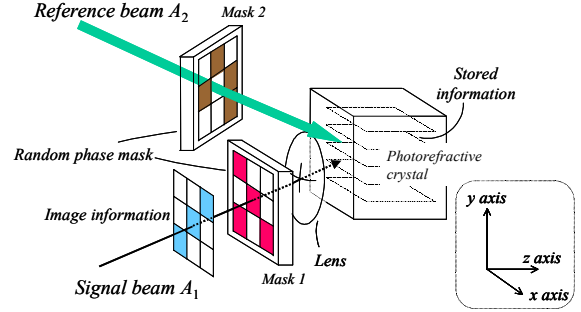
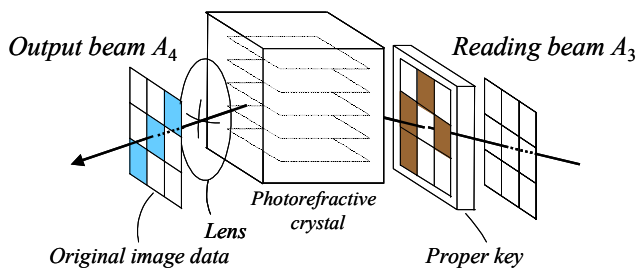
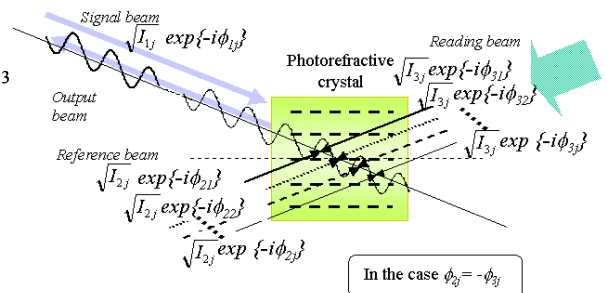


Fig.1 Recording process

Fig.2 and 3 show the decoding and the retrieving processes. The data stored in the crystal is retrieved by the illumination of the reading beam. It is generally known that the phase of the diffraction beam is represented as $\phi_4 = -\phi_1 + \phi_2 + \phi_3$. Fig.2(a) shows the retrieving process by the reading beam with the proper mask that has the conjugated phase for encoding key, that is $\phi_2 = -\phi_3$. In this case, the diffraction beams are generated from the each interaction region in phase as shown in Fig.2(b), and the original image data is retrieved. Fig.3(a) shows the retrieving process by the reading beam with the improper mask. In this case, the phase difference of the reference beam and the reading beam is not constant, and the phases of diffraction beams generated from each interaction region shift as shown in Fig.3(b). Therefore, the amplitude of each diffraction beam is negated each other, and the intensity of the output data is scarcely zero. As a result, we cannot obtain the output data by the improper key. Consequently by measuring the total output intensity, we can at a glance judge whether or not the proper key is used.



(a) Retrieving process with proper key



(b) Diffraction beam generated from each interaction region with proper key

Fig.2. The output amplitude is described as $\sum \sqrt{I_{4j}} \exp(-i\phi_{4j})$, where I_{4j} and ϕ_{4j} are the intensity and the phase of the diffraction beam in each interaction region j . The phase ϕ_{4j} is given as $\phi_{4j} = -\phi_{1j} + \phi_{2j} + \phi_{3j}$, where ϕ_{1j} , ϕ_{2j} and ϕ_{3j} are the phases of the signal beam, the reference beam and the reading beam. In case of the proper phase is given to the reading beam, that is $\phi_{3j} = -\phi_{2j}$, the phase of the diffraction beam is $\phi_{4j} = -\phi_{1j}$ and the diffraction beam generated from each region is multiple in phase.

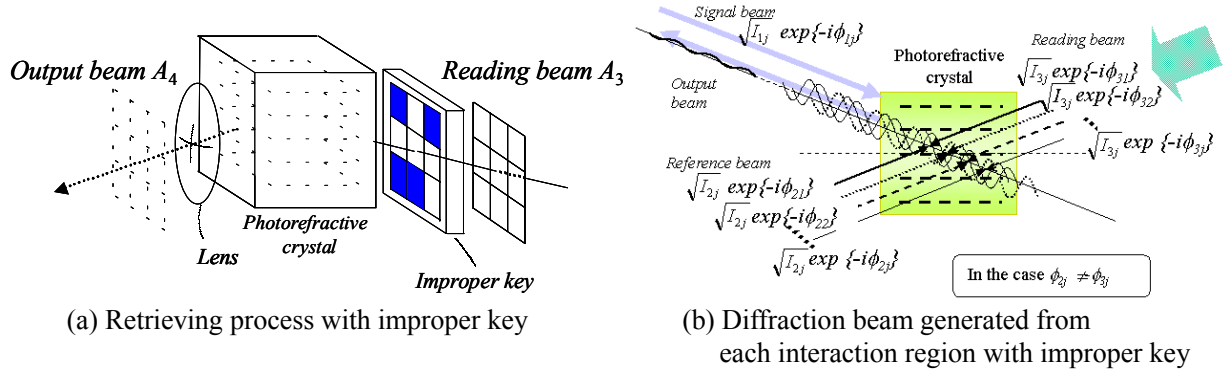


Fig.3 In case of the improper phase is given to the reading beam, the phase of the diffraction beam in each interaction region is $\phi_{4j} = -\phi_{1j} + \Delta\phi_j$, where $\Delta\phi_j = \phi_{2j} - \phi_{3j}$ is random value. As a result, the diffraction beams having random phase reduce each other and the intensity of the output beam is scarcely zero.

3. Analysis

We simulate the encoding and decoding process with consideration of the three-dimensional nonlinear response of the photorefractive medium. Fig.4 shows the optical geometry in this numerical analysis. k_1 is the wave number of signal beam and k_2 is the wave number of reference beam. θ_1 and θ_2 are the angles between the z -axis and the signal beam, the reference beam respectively. ϕ_1 and ϕ_2 are the gradient of the signal beam and the reference beam from the zx -plane respectively. We assume that the polarized vector of the input signal beam and the reference beam are \hat{e}_1 and \hat{e}_2 as shown in Fig.4. The coupling coefficient γ_{ij} between the two waves is described as follows:

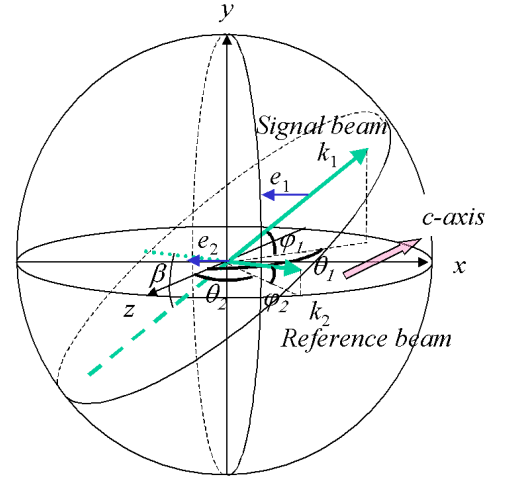


Fig.4 Optical geometry

$$\gamma_{ij} = \frac{\omega n_o^3 r_{eff} E}{2c \cos(\beta/2)} \quad r_{eff} = \frac{1}{n_o^3 n_i k_g} \left\{ \begin{aligned} &r_{13} V n_o^4 \cos \theta_1 \cos \theta_2 - r_{42} T n_o^2 n_e^2 \sin \theta_1 \cos \theta_2 \\ &- r_{42} T n_o^2 n_e^2 \cos \theta_1 \sin \theta_2 + r_{33} V n_e^4 \sin \theta_1 \sin \theta_2 \end{aligned} \right\}$$

$$V = k_1 \cos \phi_1 \cos \theta_1 - k_2 \cos \phi_2 \cos \theta_2 \quad T = k_1 \cos \phi_1 \sin \theta_1 - k_2 \cos \phi_2 \sin \theta_2$$

where c is the velocity of light, ω is the angular frequency, n_o is the index of refraction of the ordinary wave, n_i is the index of refraction of the signal beam, β is the angle between the signal beam and the reference beam, E is the electric field, r_{eff} is the Pockels coefficient, r_{13} , r_{42} and r_{33} are electro-optic coefficient and subscript i and j mean the signal beam and the reference beam that respects to various incident angle respectively. The amplitude of the output beam is described as follows:

$$A_{4ij} = \sqrt{I_{3j}(L)} \sin \left[\arctan \left\{ \exp(\ln \sqrt{P_r}) \right\} \right] - \arctan \left\{ \exp(\eta \gamma_{ij} L + \ln \sqrt{P_r}) \right\} \cdot \exp[i(\phi_1 - \phi_2 - \phi_3)]$$

$$\eta = (1 + P_r) / (1 + P_u + P_r + w) \quad w = I_c / I_2(0) \quad I_c = \sum_{i,j} |A_{1i}|^2 + |A_{2j}|^2 + |A_{3j}|^2$$

where, P_r is $I_{1i}(0) / I_{2j}(0)$, P_u is $I_{3j}(L) / I_{2j}(0)$, $I_{1i}(0)$, $I_{2j}(0)$ and $I_{3j}(L)$ are the incident intensities of the signal beam, the reference beam and the reading beam that respect to an angle component respectively, and $A_{1i}(0)$, $A_{2j}(0)$ and $A_{3j}(L)$ are the amplitudes of the signal beam, the reference beam and the reading beam that respect to an angle

component respectively.

We simulate the recording and retrieving process of the code processing of the image information. In this simulation, we assume that focal length of lens is $10.0(\text{cm})$, probe ratio $I_1(0)/I_2(0)$ is 1.0 and pump ratio $I_3(L)/I_2(0)$ is 0.1, where $I_1(0)$ is $\sum_i I_{1i}(0)$, $I_2(0)$ is $\sum_j I_{2j}(0)$ and $I_3(L)$ is $\sum_j I_{3j}(L)$. We use the 64×64 pixels image as the input information that size is $5(\text{cm}) \times 5(\text{cm})$ and the 64×64 pixels random phase mask as the encoding and decoding key.

Fig.5(a) and Fig.5(b) show the original data and the data encoded by the random phase mask of the reference beam respectively.

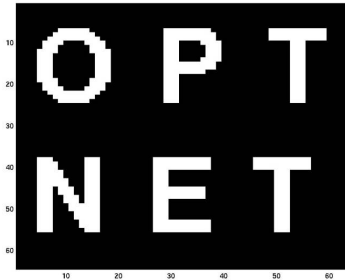


Fig.5(a) Original data

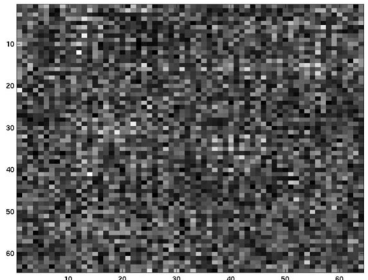


Fig.5(b) Encoded data

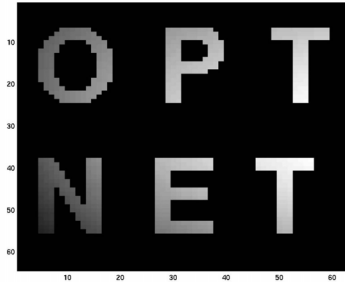


Fig.5(c) Retrieved data
with proper key



Fig.5(d) Retrieved data
with improper key

Fig.5(c) shows the retrieved data with the proper key. We confirm that the decoded data is restored to its original state with certain degree of accuracy though the partial decline of the intensity is observed because of the directional dependence of the coupling coefficient. Fig.5(d) shows the retrieved data without the decoding key. The output beam is hardly generated and the retrieved data cannot be obtained. Therefore, the only user who has the proper key can read out the information and we can at a glance judge by measuring the total output intensity whether or not the proper key is used. By using this technique, we can realize the all-optical memory with authentication and unlawful access detection using photorefractive four-wave mixing.

4. Conclusion

We have proposed the all-optical memory with authentication and unlawful access detection using photorefractive four-wave mixing. By simulation of the recording and retrieving process, we show that the decoded data is generated and restored to its original state by the reading beam with the proper key, and that the output data is hardly generated by the reading beam with the improper key. Consequently we can at a glance judge whether or not the proper key is used by measuring the total output intensity, and can realize the photorefractive holographic memory with authentication and unlawful access detection theoretically.

Reference

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